



Weak Gravitational Lensing in the Laboratory

**Status Update
to
Weak Lensing Science GREAT-10 meeting**

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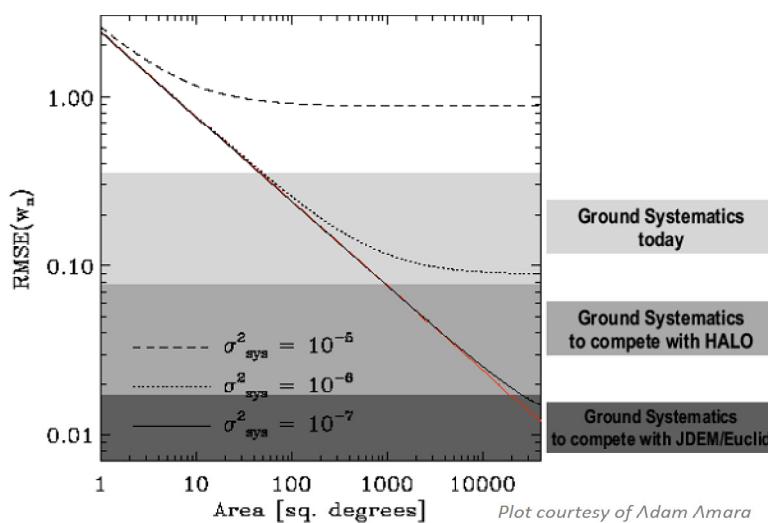
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overview

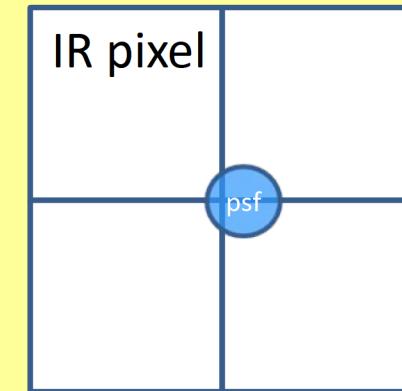
Weak lensing measurement requirements

Very stringent error budgets



Without control of systematic errors, the mission will fail

Proposed missions
plans require
undersampled PSFs



- Estimated PSF undersampling for Omega-X DRM
- Plate scales
 - WFIRST -- 0.18"
 - Euclid -- 0.31"

Requirements make WL *hard* to do, even in the lab !

Detector issues for WL

- **Detector must not prevent accurate recovery of PSF from undersampled data**
- **Detector must not imprint different ellipticity on galaxies as on stars used as PSF calibrators**
- **Non-shape measurement issues**
 - Photometric accuracy (e.g. photo-z)
 - Shrinking pixel hypothesis (PSF deconvolution)

Hazards for CCDs ?...

- CTE and its rate of change with radiation damage. Change in CTE with signal
- Row-column difference in pixel size variability.
- Pixel size dependence on signal?
- Transient response on video.
- Image persistence, if any
- Intrapixel response variation

Hazards for IR arrays ?...

- Interpixel capacitance.
- Reciprocity failure and linearity.
- Image persistence when dithering.
- Row-column difference in pixel size variability.
- Pixel size dependence on signal.
- Transient response on video.

Precision projector helps weak lensing missions by ...

- 1. Identifying important design constraints for Design Reference Mission (DRM) concepts for any WL experiment**
 - Impact of image plate scale variations
 - Develop methods to correct for detector-induced errors and/or algorithms that may relieve (or define) major cost trades
- 2. Answering critical questions for Science Definition Teams**
 - Understand degree to which undersampled PSF affects galaxy shape measurements
 - Quantify detector induced errors
 - Measure/correct for induced PSF variation with real detectors
 - Verify requirements of PSF calibration star density and thus temporal stability of PSF

Real world validation of calibration and image processing algorithms. ... not just with simulated images

- To be meaningful, observing conditions must be emulated (f-number, undersampling, dither patterns, image recombination algorithms)
- Initially we make the PSFs very good so we don't need to measure and deconvolve spatially varying PSF shapes.

To prove we can do it , even in the lab, we need to ...

- **produce extremely well controlled PSFs**
so we can understand detector induced errors and how to correct for them
- requires large data sets, automated acquisition and processing and development/validation of algorithms.

New paradigm

- Integrated Science & Engineering team
- Collaboration with scientists crucial to the success of this effort

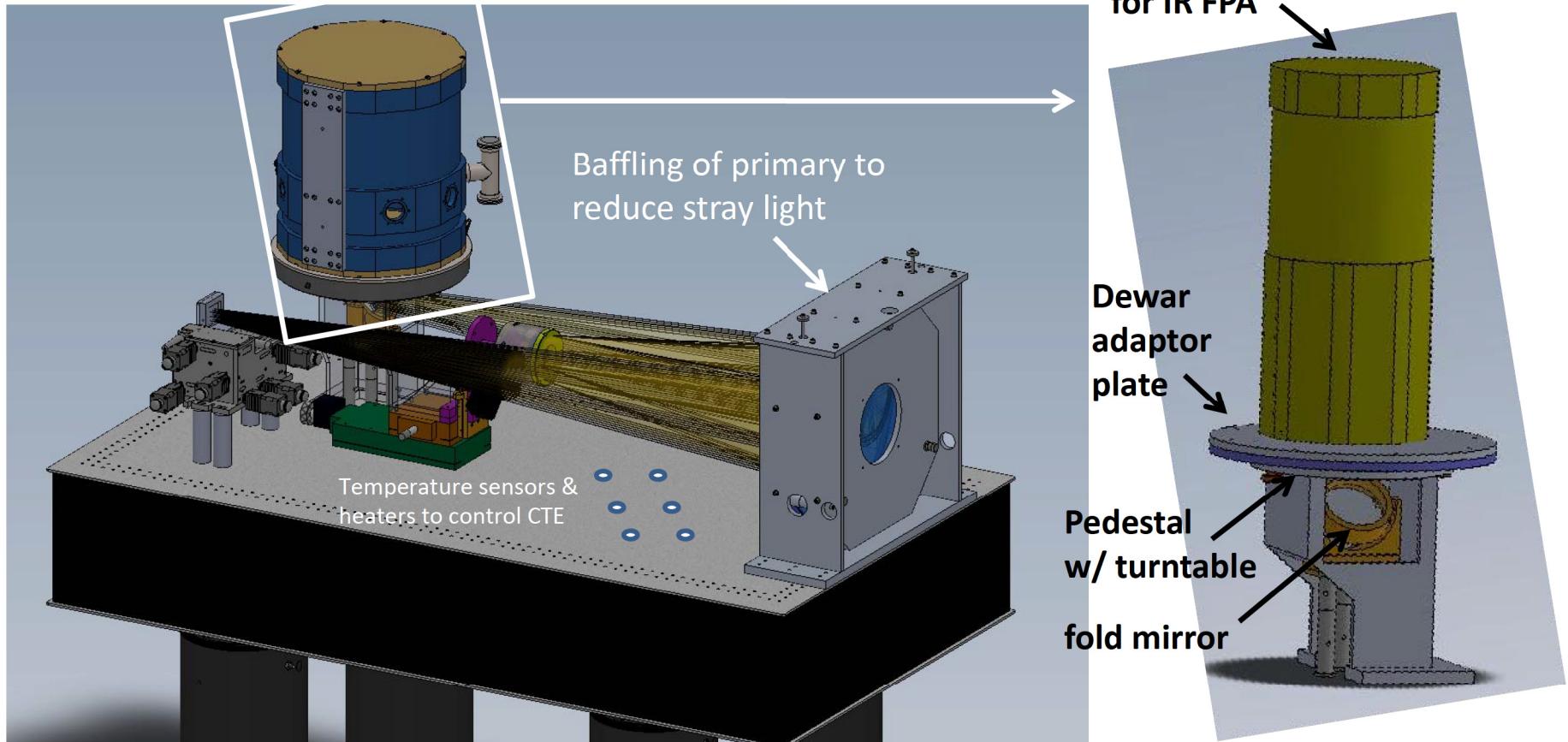
Projector development plan

- **PHASE 1 – Baseline infrastructure development**
 1. Design/build/assemble optics
 2. Develop analysis algorithms, test automation and data visualization
 3. Demonstrate ability to efficiently project simulated stars & galaxies
- **PHASE 2 – Partition errors between mask, optics and detector**
 1. Validate system capability for shape measurement w/ “well-resolved” imager
 2. Repeat with undersampled CCD with smaller pixels
 3. Repeat for the NIR detector
- **PHASE 3 – Apply calibrations**
 1. Imprint ellipticity to show how much detector (de)magnifies ellipticity
 2. Show to what extent PSF varies due to change in pixel properties
 3. Separate detector-induced ellipticity
 4. Determine the extent to which detector-induced errors can be suppressed by calibration
- **PHASE 4 — Explore different image scales, etc**
 1. Measure ellipticity errors vs Science Definition Team cost trades
 2. Test PSF deconvolution for PSF variation and star densities

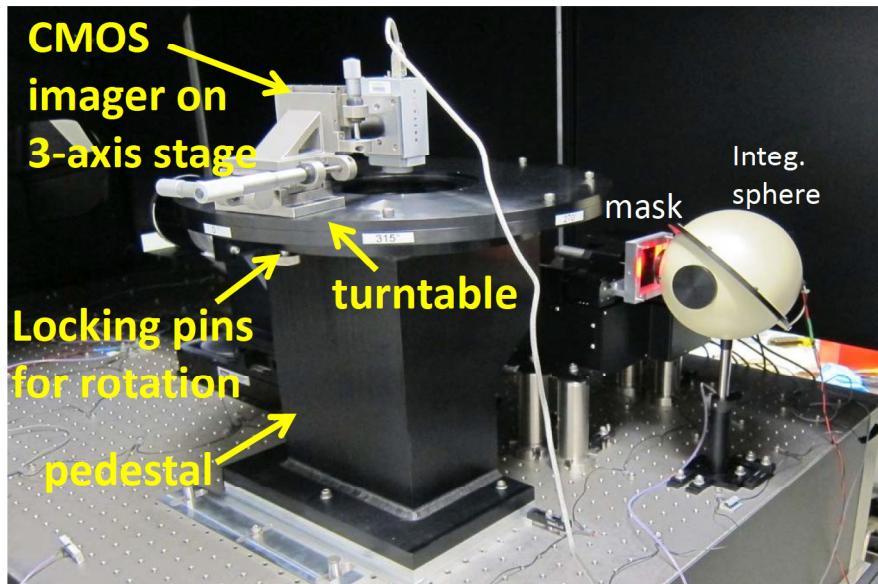
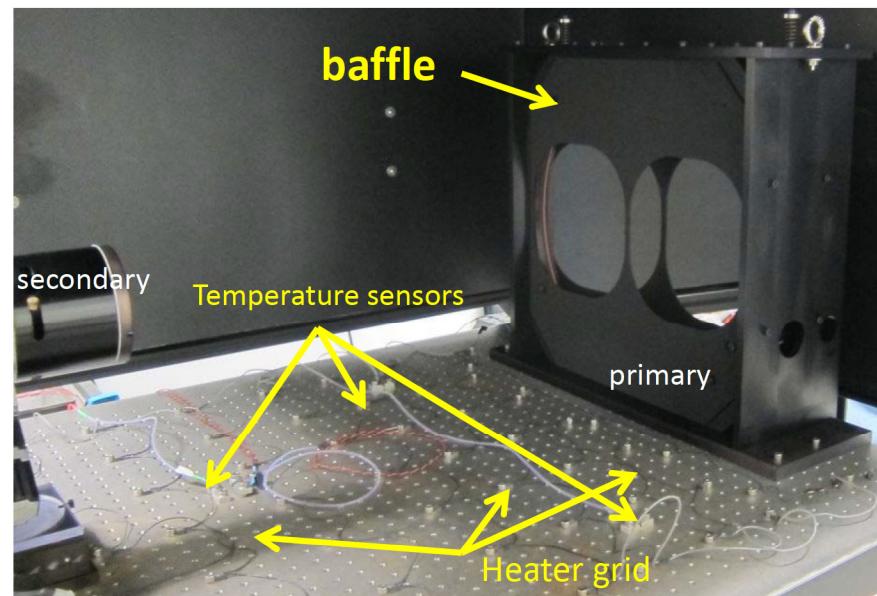
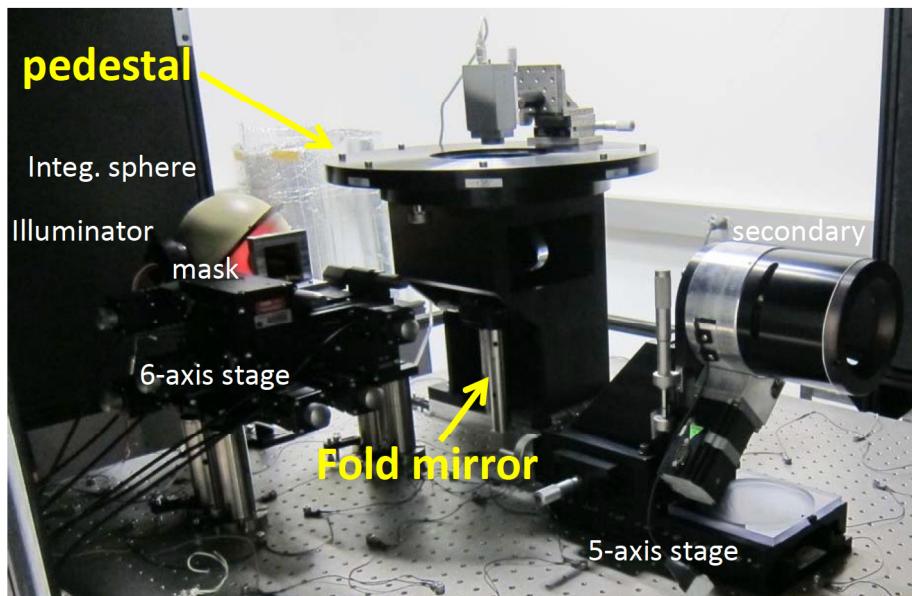


Projector

Precision Projection System Design



Projector



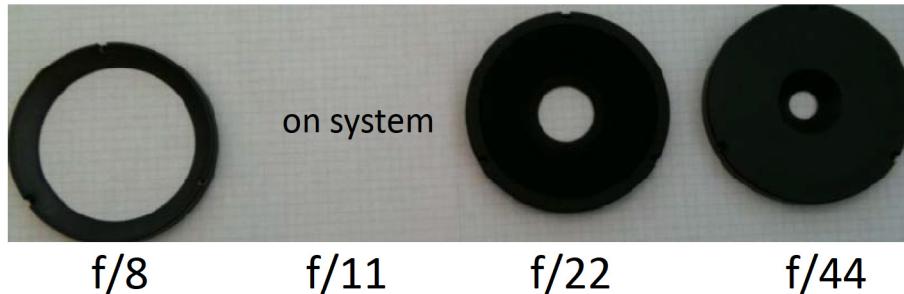
Control parameters

- Optics
 - PSF (Illum. wavelength & f/#)
 - Ellipticity (at either pupil or object plane)
- Spot masks at object plane
 - Rotation & translation (6-axis)
- Detector at image plane
 - CMOS, CCD, IR
 - Rotation (0 – 360 deg.)

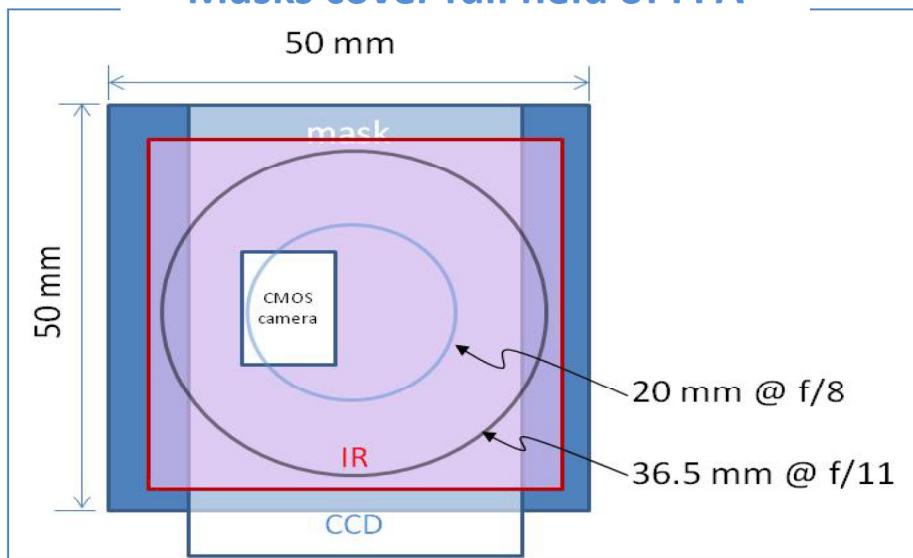
PSF and object size control

In the optics

Pupil stops for secondary mirror



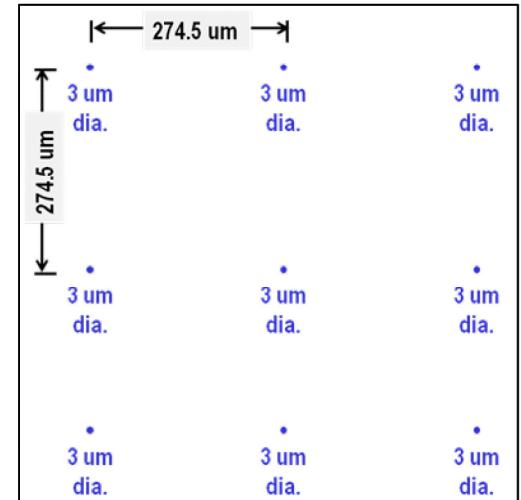
Masks cover full field of FPA



>15,000 spots per image

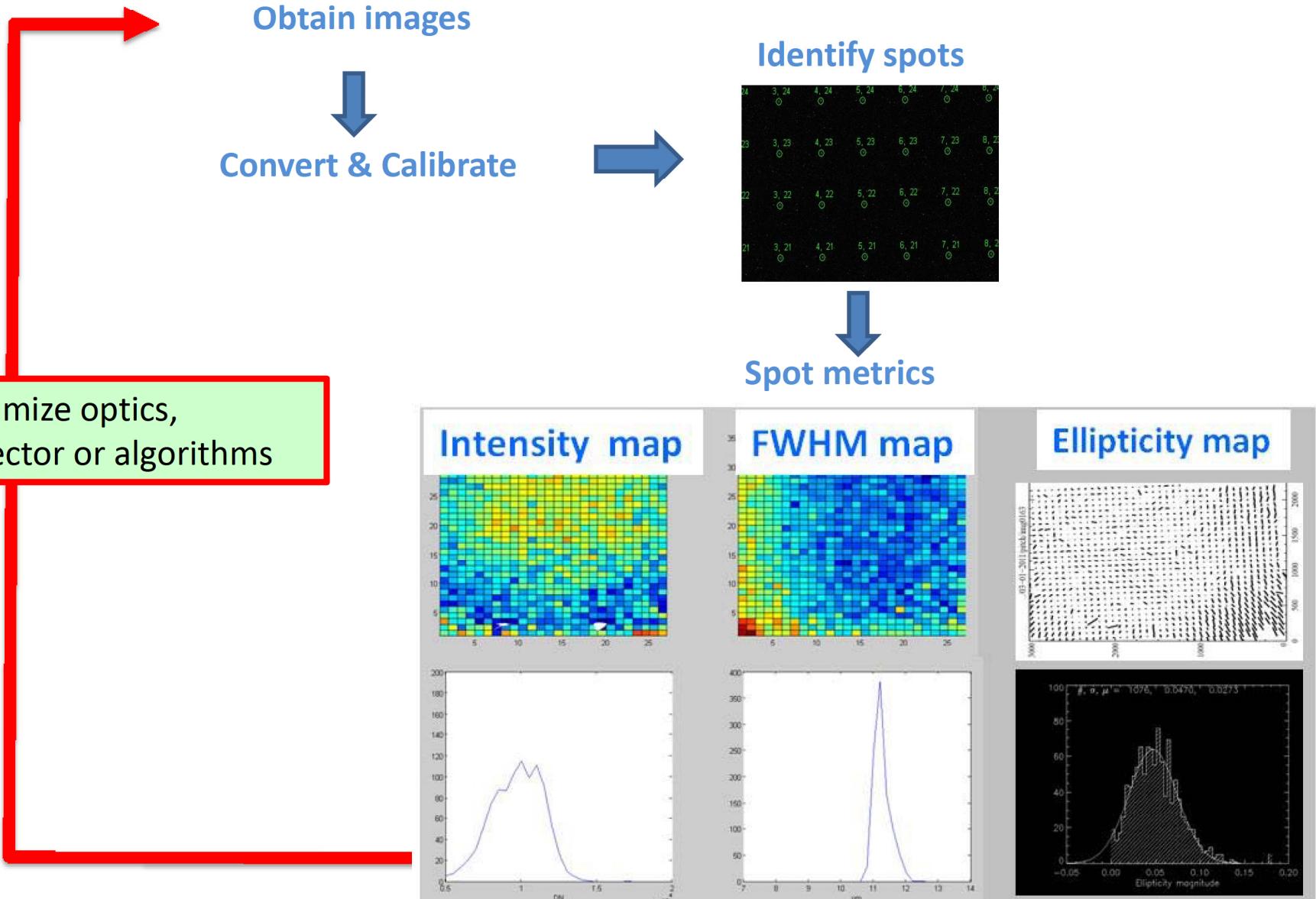
At the object plane

Spot mask

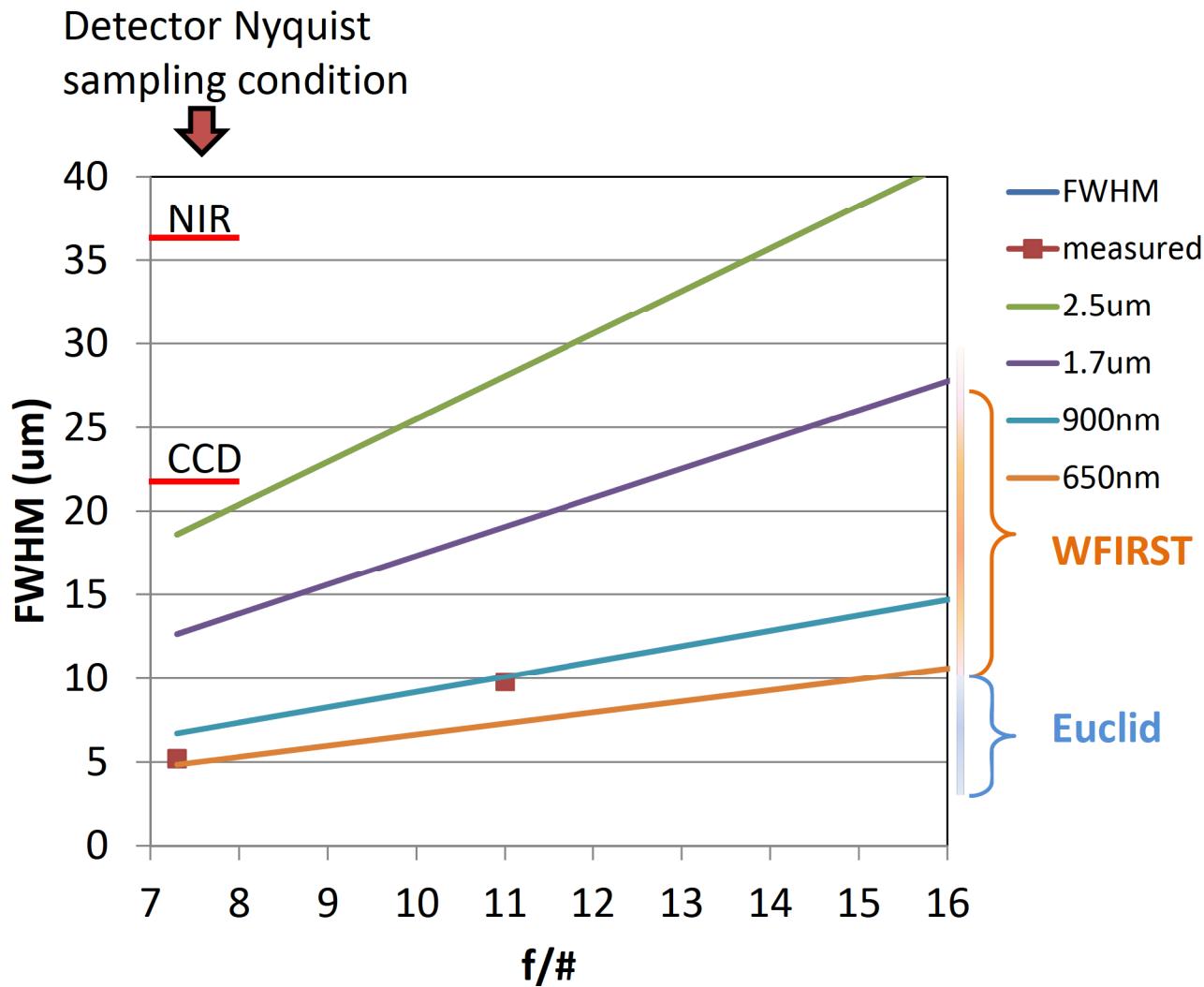


- **Psf range spans undersampled to well-resolved**
 - **Undersampling range spans both Euclid & WFIRST**
 - CCD
 - NIR

Image data analysis procedure



Achievable PSF range spans mission design scenarios



Results

Summary of the data

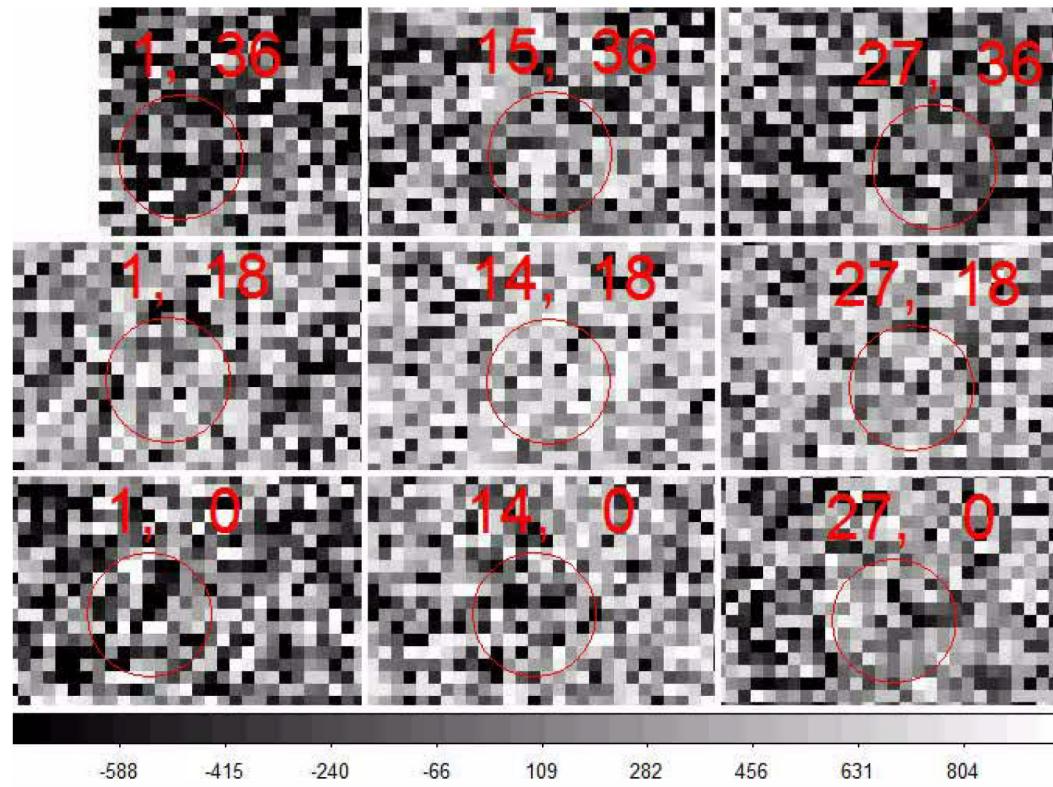
- **Testing with well-resolved spots**
 - First iteration is reaching its limits – this is good →
 - Focus to within $\frac{1}{4}$ pixel under near-nyquist sampling
 - Uncorrected ellipticities currently $\sim 3\%$
 - Measurements limited by (SNR, image motion, etc.)
 - Improvements identified (mechanical, shorter exposures, higher illum. sources)
 - Implementation TBD
 - Data in hand to help decomposition of error sources
 - Analysis pending
- **Testing with under-sampled spots**
 - CCD installation to start this week
 - Testing planned for next three weeks
 - NIR installation planned for mid-Oct

Iterative process to develop methodology to identify and beat down error limits

Well-resolved images

Focus experiment

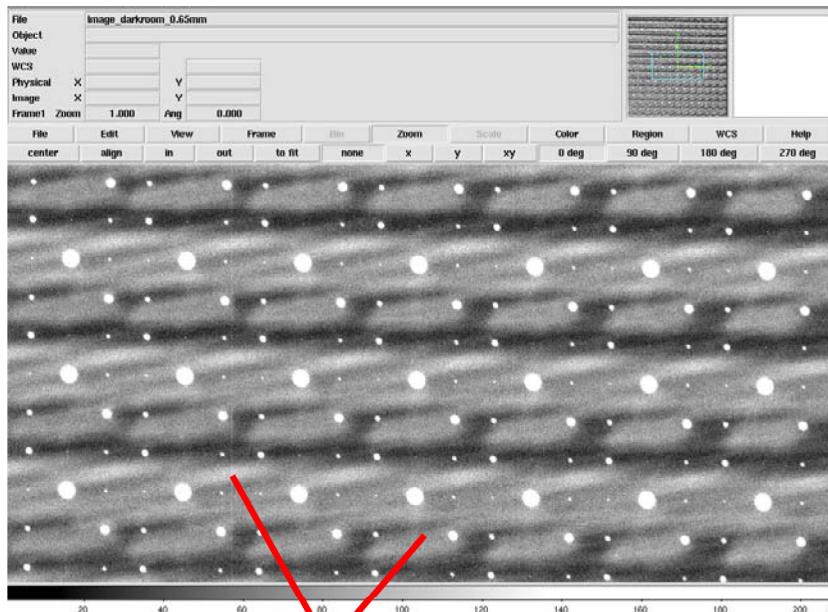
Movie: 100 frame focus sequence (single axis)



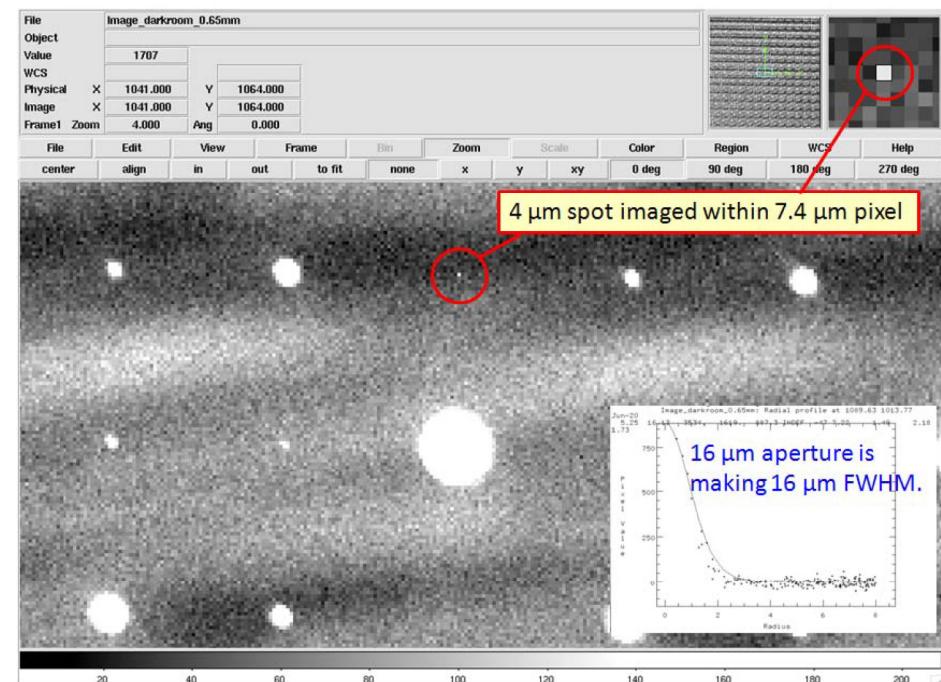
- Data are calibrated for Bias, Dark & flat field

First light

(circa Jun 2010)

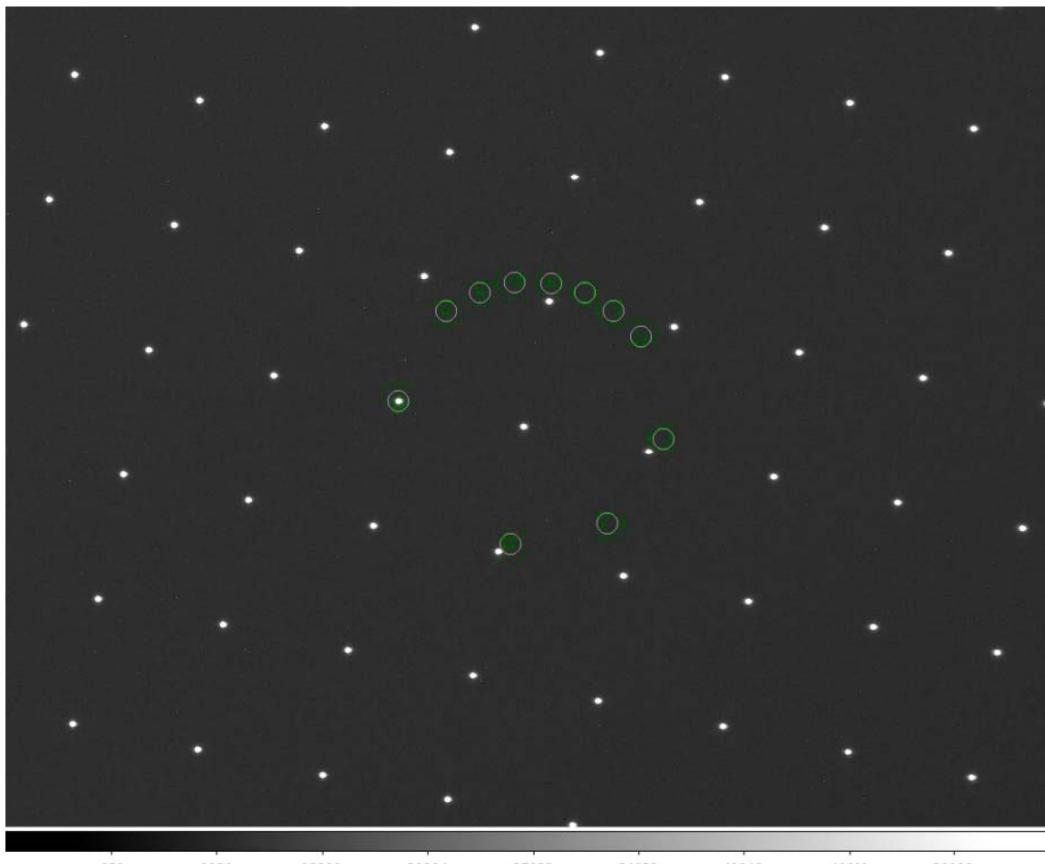


Ghosts between diffractive frontside of CCD and highly reflective input mask.



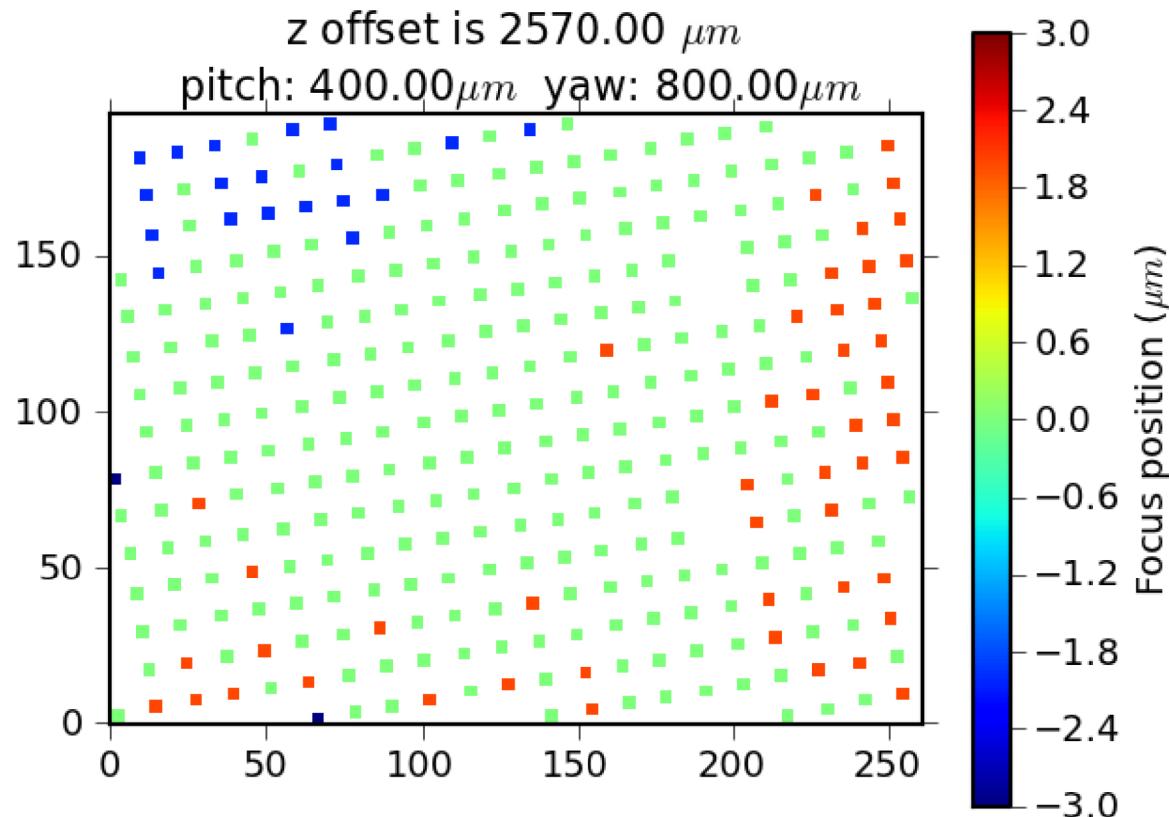
Initial raw images, rough focus, no darks or flats

Greatly improved image (Sept 2011)



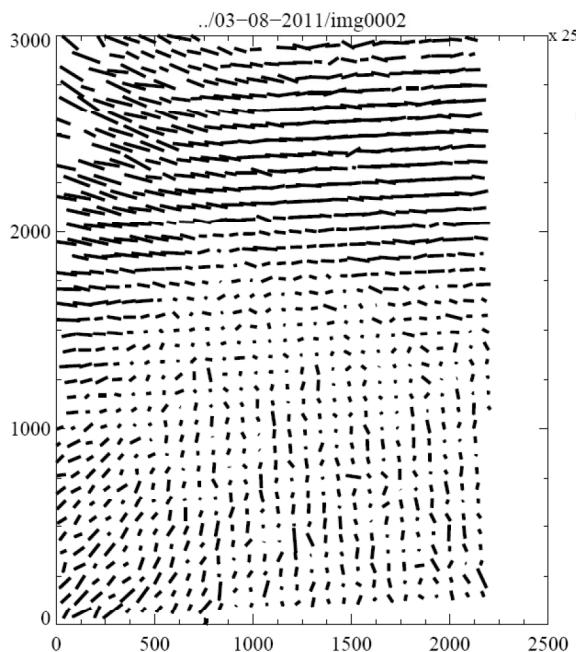
- **Rotational stability of pedestal bearing w/ CMOS imager**
 - Angular variation $<0.006^\circ$
- **Need to identify spot motion due to rotation**
 - Developed spot motion tracker S/W algorithm

Focus precision

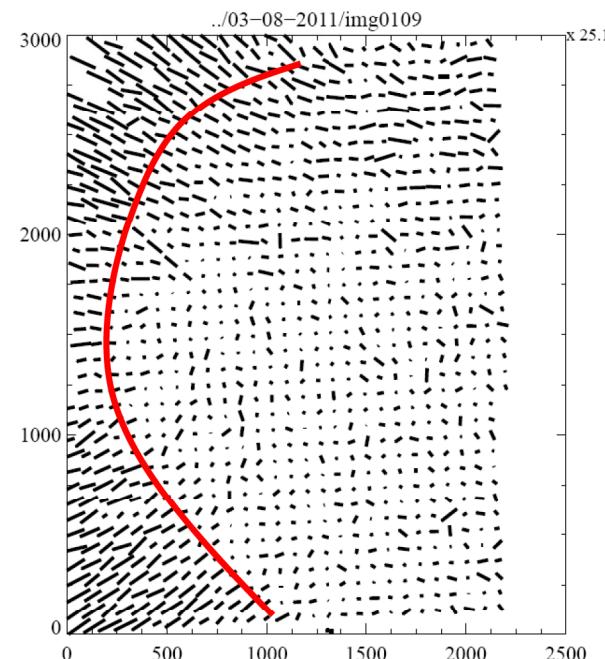


Ellipticity variation due to mis-focus

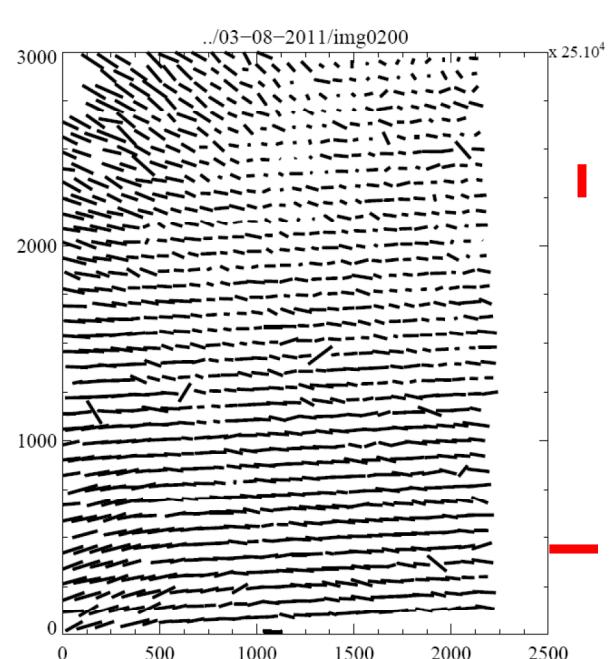
Out-of-focus



Best focus

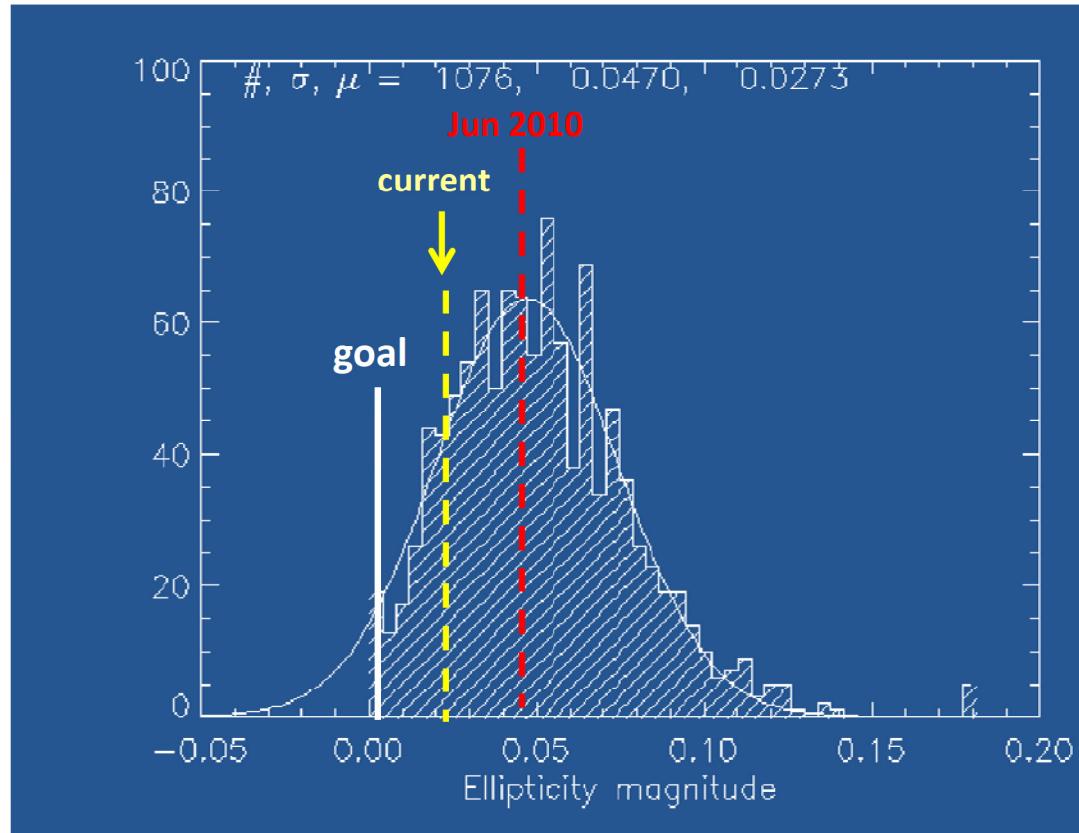


Out-of-focus



- Ellipticity reversal around center is obvious
- Some, yet unidentified aberrations in corners of image

Ellipticity measurement



- Measured ellipticity improved to ~2%
- Breakdown into optical, mask & detector components in process